(72) Inventor: Hu, Shane Ching-Feng
Beaverton, Oregon 97008 (US)

(74) Representative:
Molyneaux, Martyn William
Langner Parry
52-54 High Holborn
London WC1V 6RR (GB)

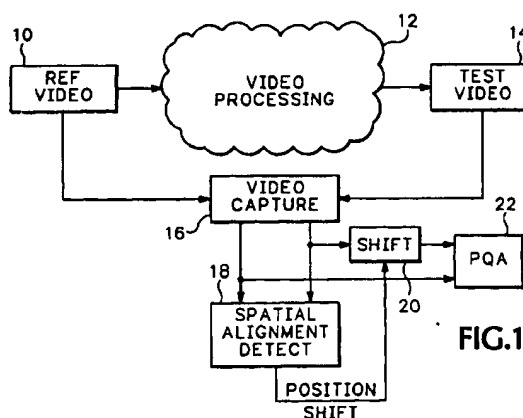(54) **High precision sub-pixel spatial alignment of digital images**

(57) A high precision sub-pixel spatial alignment of digital images, one from a reference video signal and another from a corresponding test video signal, uses an iterative process and incorporates spatial resampling along with basic correlation and estimation of fractional pixel shift. The corresponding images from the reference and test video signals are captured and a test block is overlaid on them at the same locations to include texture from the images. FFTs are performed within the test block in each image, and the FFTs are cross-correlated to develop a peak value representing a shift position between the images. A curve is fitted to the peak and neighboring values to find the nearest integer pixel shift position. The test block is shifted in the test image by the integer pixel shift position, and the FFT in the test image is repeated and correlated with the FFT from the reference image. The curve fitting is repeated to obtain a fractional pixel shift position value that is combined with the integer pixel shift value to update the test block position again in the test image. The steps are repeated until an end condition is achieved, at which point the value of the pixel shift position for the test block in the test image relative to the reference image is used to align the two images with high precision sub-pixel accuracy.

FIG.1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to the matching of digital images, and more particularly to high precision sub-pixel spatial alignment of digital images.

[0002] Accurate spatial alignment of digital images is of fundamental importance to many applications. One such application is the determination of picture quality using an instrument, such as the PQA200 Picture Quality Analyzer manufactured by Tektronix, Inc. of Wilsonville, Oregon, USA, where images from a reference video signal are compared with corresponding images from a test video signal that is a processed version of the reference video signal. The better the spatial alignment between a reference image and a corresponding test image, the more accurate the determination of the amount of degradation of the test video signal due to the processing.

[0003] At pages 480-484 of Computer Image Processing and Recognition (1979) published by Academic Press, Ernest L. Hall describes a basic correlator method for template matching, which may be used for image alignment. Likewise J.J. Pearson et al in an article entitled Video-Rate Image Correlation Processor (IOCC 1977) published in SPIE Vol. 119Application of Digital Image Processing, pages 197-205, describe a variant of the basic correlator method that uses phase information. For digital images with integer pixel shifts these correlation methods may be very accurate. However for a broader class of shifts, which involves both integer and fractional pixel shifts, the precision of the sub-pixel alignment becomes a very serious matter. Pearson et al describe a method for estimating the sub-pixel shifts by quadratic interpolation using the correlation values in the neighborhood of a peak. However, since the quadratic interpolation function does not necessarily match the true image shifting function, the accuracy obtained by the quadratic interpolation is limited.

[0004] What is desired is a high precision sub-pixel spatial alignment of digital images.

BRIEF SUMMARY OF THE INVENTION

[0005] Accordingly the present invention provides for high precision sub-pixel spatial alignment of digital images using an iteration method and spatial resampling. A high precision sub-pixel spatial alignment of digital images, one form a reference video signal and another from a corresponding test video signal, uses an iterative process and incorporates spatial resampling along with basic correlation and estimation of fractional pixel shift. The corresponding images from the reference and test video signals are captured and a test block is overlaid on them at the same locations to include texture from the images. FFTs are performed within the test block in each image, and the FFTs are cross-correlated to develop a peak value representing a shift position between the images. A curve is fitted to the peak and neighboring values to find the nearest integer pixel shift position. The test block is shifted in the test image by the integer pixel shift position, and the FFT in the test image is repeated and correlated with the FFT from the reference image. The curve fitting is repeated to obtain a fractional pixel shift position value that is combined with the integer pixel shift value to update the test block position again in the test image. The steps are repeated until an end condition is achieved, at which point the value of the pixel shift position for the test block in the test image relative to the reference image is used to align the two images with high precision sub-pixel accuracy.

[0006] The objects, advantages and other novel features of the present invention are apparent from the following detailed description when read in conjunction with the appended claims and attached drawing.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0007] Fig. 1 is a block diagram view of a system for high precision sub-pixel spatial alignment of digital images according to the present invention.

[0008] Fig. 2 is an illustrative view of a comparison of an image from a reference video signal and an image from a corresponding test video signal to be spatially aligned with high precision sub-pixel accuracy according to the present invention.

[0009] Fig. 3 is a flow diagram view of a high precision sub-pixel spatial alignment algorithm according to the present invention.

[0010] Fig. 4 is an illustrative view of a cross-correlation surface showing a peak location for the high precision sub-pixel spatial alignment algorithm according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] Referring now to Fig. 1 an original, reference video signal from a source **10** is input to a video processing network **12**. The video processing network **12** may include one or more compression/decompression passes. The output from the video processing network **12** is input to a decoder or similar device **14** to provide a source of a test video signal. The reference and test video signals are input to a video capture module **16** that captures corresponding images or frames from the two video signals. The corresponding image pairs from the video capture module **16** are input to a high precision sub-pixel spatial alignment detect module **18** to determine a position shift between the images of the reference video signal and the images of the test video signal. The position shift from the spatial alignment detect module **18** is input to a position shift module **20**, which may be either in the reference or test signal path, to

precisely align the image pairs with sub-pixel accuracy from the video capture module **16** for further processing, such as by a picture quality analyzer **22**.

[0012]   In Fig. 2 the reference and test images **24, 26** are shown having some texture **25**, i.e., not a matte image. As shown in the test image after processing the texture **25** has been shifted horizontally and/or vertically. An arbitrary test region or block **28** is formed, shown in this example as a rectangle, having a reference point Xo, Yo and is overlaid on both the reference and test images. For a rectangle as shown the reference point and horizontal and vertical extents ΔX, ΔY define the test region or block28. The test region **28** is located where there is substantial texture **25** in the images.

[0013]   A high precision sub-pixel spatial alignment algorithm is shown in Fig. 3. An initialization module **30** provides the corresponding reference and test images together with a test block to a correlation measurement module **32**. The first step **34** in the initialization module **30** controls the video capture module **16** to capture corresponding reference and test images or frames from the reference and test video signals. The second step **36** establishes a test block for overlaying on the respective images in an area that has significant texture **25**. The first step **38** of the correlation measurement module **32** applies a fast Fourier transform (FFT) to the pixels of the images that lie within the test region. A cross-correlation step **40** is then performed in the FFT domain.

$$FFT(corr) = FFT(ref)^*FFT(tst)$$

$FFT^{-1}\text{à}(corr)$ produces correlation coefficients for every shift point within the test region, which may be represented in the form of a surface **42** as shown in Fig. 4. The position of a peak **44** in the surface **42** indicates the amount of shift in position between the reference and test images. A curve-fit step **46** provides a nearest integer pixel shift position for the peak44 based upon the coefficients for the peak position and the positions up, down, left and right from the peak position. The pixel shift position from the correlation measure module **32** is input to an update shift position step **48**. For the first iteration only the nearest integer pixel shift position is used.

[0014]   A testing step **50** checks the amount of position shift determined from the update shift position step **48** and the number of iterations against specified parameters to determine whether the spatial alignment algorithm is done. If the number of iterations is equal to the specified number, or the amount of update is less than a specified noise value, then the shift position value from the update step **48** is provided as an output pixel shift position and the algorithm ends. Otherwise a shift test block step **52** shifts the test region in the test image by the value from the update position step48 so that the reference point is shifted to be $X+X_A$, $Y+Y_A$, where X_A and Y_A are the integer pixel shift position values. With the new position of the test region or block, the correlation module **32** is applied again to obtain a fractional pixel shift value in X and Y. In the FFT step **38** only the test image is processed after the initial iteration. The FFT for the reference image does not change. The fractional pixel shift value is used to update the shift position in the update step **48** so that the shift position becomes $Xo+X_A+X_f$, $Yo+Y_A+Y_f$. It has been found that for most practical applications two fractional pixel shift position iterations produce satisfactory results. The final shift position value output from the spatial alignment detect module **18** is then used to spatially align the test and reference images as indicated above.

[0015]   Thus the present invention provides high precision sub-pixel spatial alignment of digital images by using an iterative process to cross-correlate FFTs for a test block from each image in order to find a peak representative of a shift position between the images, then by fitting a curve to the correlation coefficients to determine a nearest integer pixel shift position, updating the position of the test block in the test image and repeating until a specified number of iterations occurs or a change in fractional pixel shift position is less than a noise value.

Claims

1.   A method of high precision sub-pixel spatial alignment of digital images comprising the steps of:

capturing a reference image from a reference video signal as one of the digital images and a corresponding test image from a test video signal as another of the digital images, where the test video signal represents the reference video signal after processing;

overlaying an arbitrary test block on the reference and test images at corresponding locations that include texture;

performing a fast Fourier transform for the portions of each image that lie within the test block to produce a reference FFT and a test FFT;

cross-correlating the reference and test FFTs to produce a correlation surface having a peak correlation value, the position of the peak correlation value on the correlation surface being representative of a shift position between the reference and test images;

fitting a curve to the peak and neighboring correlation values to determine an integer pixel shift position;

updating the position of the test block overlaying the test image by the integer pixel shift position; and

repeating the performing step for the test image, the correlating step for finding fractional pixel shift positions, and the updating step by adding the fractional pixel shift positions to the integer pixel shift

position until an end condition is achieved, the final position of the test block in the test image from the updating step relative to the initial position of the test block in the test image providing the high precision sub-pixel shift alignment between the reference and test images.

2. A method of high precision sub-pixel spatial alignment of digital images comprising the steps of:

cross-correlating in the frequency domain a test block for each of the digital images to produce a correlation surface having a peak correlation value at a particular position within the test block;

updating the test block in one of the digital images as a function of the particular position; and

repeating the cross-correlating and updating steps until a specified end condition is achieved, the final position of the test block in the one of the digital images relative to the other digital image representing the high precision sub-pixel spatial alignment between the digital images.
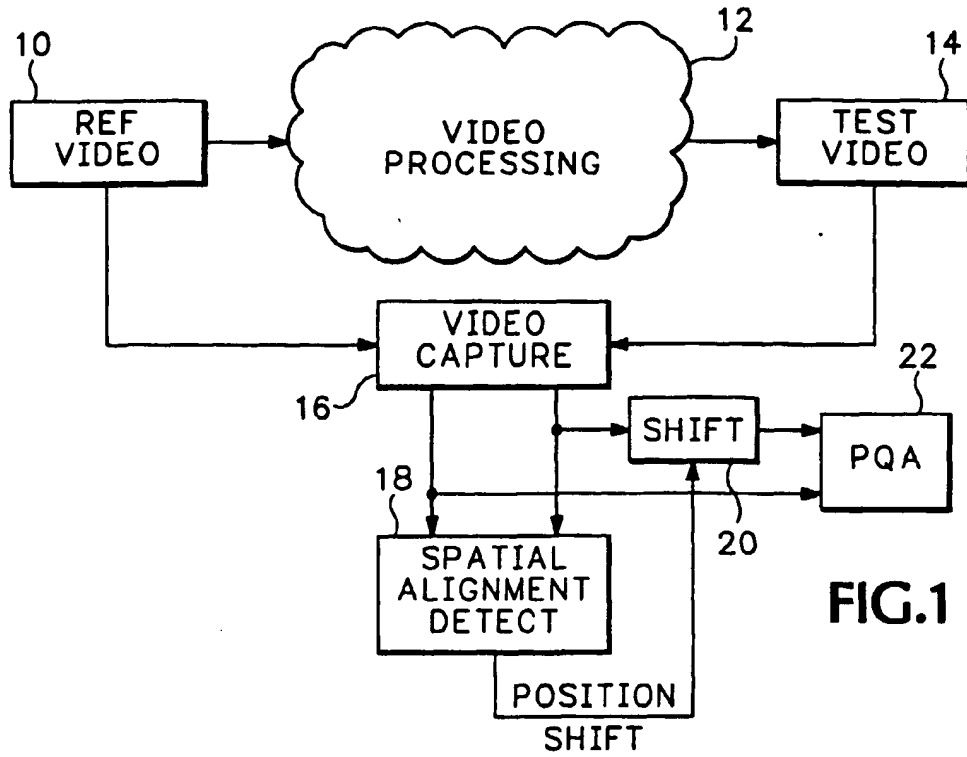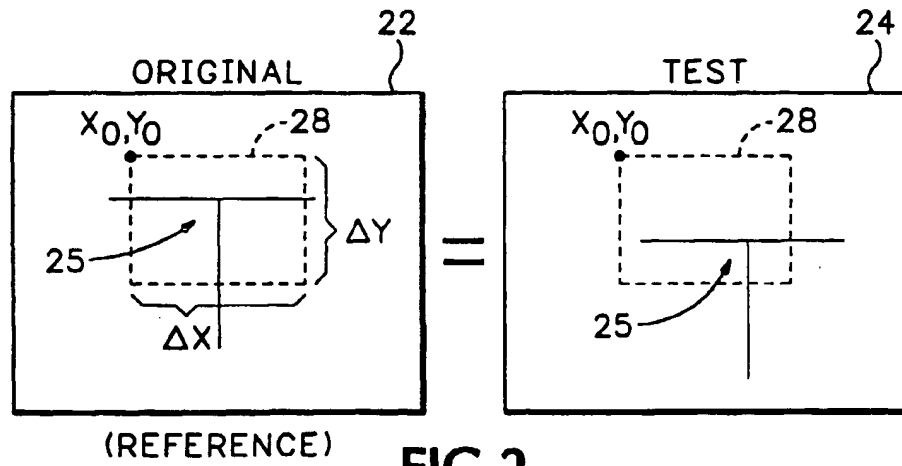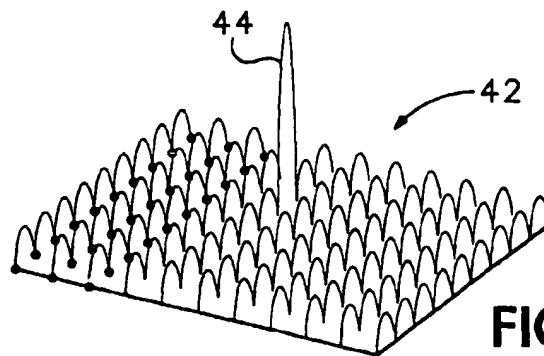
FIG.1

(REFERENCE) **FIG.2**

FIG.4

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                          ┌──────────────────┐
                          │     SPATIAL      │
                          │   CORRELATION    │
                          │      START       │
                          └──────────────────┘
                                   │
                                   ▼
                          ┌──────────────────┐
                          │    INITIALIZE    │  ┐
                     34───│   ACQUIRE REF &  │  │
                          │   TEST FRAMES    │  │
                          └──────────────────┘  │
                                   │            ├─ 30
                                   ▼            │
                          ┌──────────────────┐  │
                          │  ESTABLISH TEST  │  │
                     36───│ BLOCK W/TEXTURE  │  ┘
                          └──────────────────┘
```

SHIFT TEST PEAK PER SHIFT LOCATION (INTEGER ONLY FIRST ITERATION) — 52

CORRELATION MEASURE PERFORM FFTS W/I TEST BLOCKS FOR REF & TEST FRAMES — 38

CROSS-CORRELATE FFTS TO FIND PEAK LOCATION — 40

32

QUAD CURVE-FIT FOR FRACTIONAL PIXEL POSITION ABOUT PEAK LOCATION — 46

DONE ? — 50   NO

UPDATE SHIFT POSITION (INTEGER SHIFT ONLY FIRST ITERATION) BASED UPON CURVE FIT — 48

YES

END POSITION SHIFT

FIG.3